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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

This Issue

EXTREME PRESSURE LUBRICANTS

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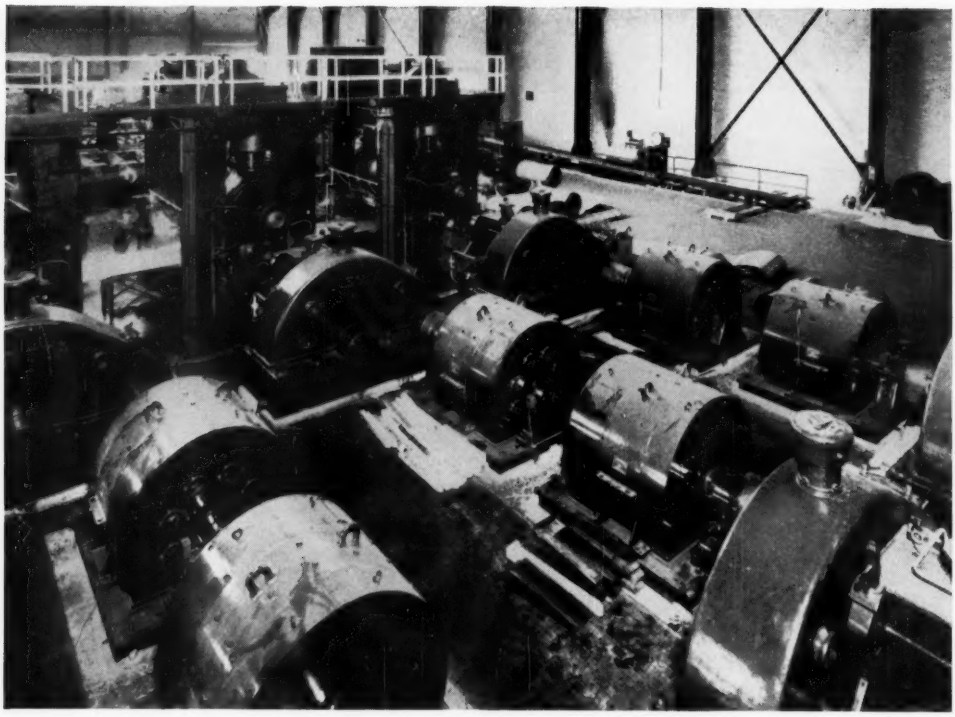

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LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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EXTREME PRESSURE LUBRICANTS

THE IMPORTANCE of the proper selection and use of lubricants to reduce the undesirable effects of boundary lubrication has been recognized for many years. Matching the lubricant to the specific machine and operating conditions of the user continues to receive more attention. The equipment operator has become aware that savings from reduced maintenance and replacement expenses can more than compensate for the added cost of high quality lubricants designed for a specific application.

The significance of the economy which can be obtained in this direction can be appreciated by considering the amount of research which has been devoted to the study of this subject. Academic groups, equipment manufacturers, the lubricant industry, and consumers have spent untold numbers of manhours and dollars studying the fundamental and practical concepts of boundary lubrication and lubricants. This has been done not only to make existing machines and lubricants compatible, but also to design new machines to evaluate and take advantage of the improved characteristics of newly developed lubricants. A recent literature survey of friction and boundary lubrication resulted in a compilation of 1212 articles published on this subject! While this is an impressive figure, it is obvious that much additional work has been done and not published.

In spite of all the work that has been done (or perhaps because of it) there is still disagreement on the mechanism by which EP (extreme pressure) and boundary lubricants function. Perhaps this merely indicates that a single explanation cannot account for all the phenomena which have been observed. It is interesting to note that while men disagree as to how or why lubricants work, machines disagree with regard to which lubricants give the best results. Numerous testing devices have been developed for evaluating EP properties of lubricants. Almost without exception it has not been possible to correlate quantitatively one type of tester with another. On the other hand, qualitative correlations have been found to exist since each recognized tester has been capable of differentiating between additive and non-additive lubricants.

Although difficulties and contradictions have been encountered, significant progress has been made in understanding the nature of EP lubricants and in applying them to produce more efficient designs of machinery with longer and more productive lives. Increased production rates and increased life have also been made possible with older equipment by the same means. Clear thinking people have recognized that although knowledge of boundary lubrication is far from complete, the information that is available can be used to enable designers and operators to proceed with ideas that would be considered ridiculous with ordinary lubricants.

The purpose of this article is to review some of the theories of boundary lubrication, to discuss some

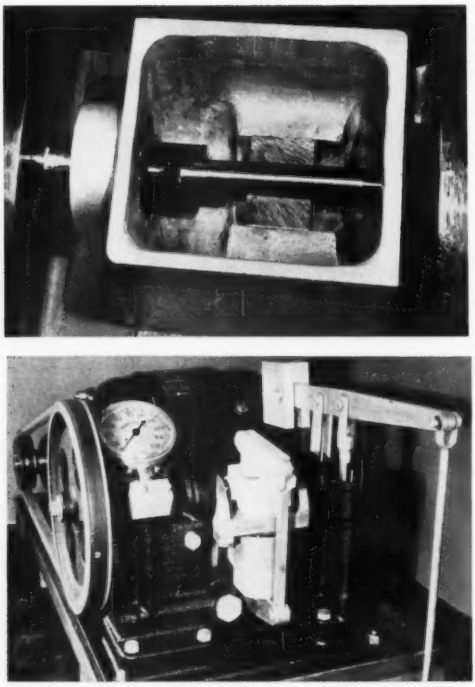

Figure 1 — The Almen EP Lubricant Testing Machine. The upper view shows the test specimen boat with the test pin and one-half the test bushing installed.

of the tests used for evaluating EP lubricants, and to describe some of the principal applications of lubricants having EP properties.

NEED FOR EP LUBRICANTS

The basis for the design of journal bearings is in the fact that a lubricant can be made to form a fluid film separating two surfaces which slide over each other. However, for this to take place the combination of speed, load, and lubricant viscosity must be within a rather broad, but definite range. Increasing speed or lubricant viscosity produces a thicker film and increasing load reduces the film thickness as long as the geometry of the bearing surfaces is fixed. Bearings are designed to permit maintaining a fluid film under most of the operating conditions which might be encountered. However, it is obvious that when movement between the bearing surfaces approachs zero, when high shock loads are imposed, or when excessive temperatures reduce viscosity to too low a level, a complete fluid film cannot be maintained between the bearing and journal and metal-to-metal contact occurs.

Spur gears are designed to provide line contact between two mating teeth which ideally roll over each other without sliding. This ideal design is never actually realized because the elasticity of metals produces area contact rather than line contact. Also, some sliding must result when the teeth deflect as they engage and then return to their normal shape when they unmesh. In addition, machining imperfections would prohibit the achievement of pure rolling between the teeth even if the gear materials were completely rigid. Therefore, the meshing and unmeshing of gear teeth might be considered analogous to the operation of a journal bearing with rapidly changing speed and load and probably variable viscosity due to localized surface heating of the gear teeth. Under relatively mild operating conditions, a fluid film can be established on the gear teeth. However, under severe operating conditions, a fluid film cannot be maintained and boundary or EP lubricants are required for satisfactory operation. The conditions requiring an EP lubricant are not always sharply defined, and in many cases one must rely on previous experience or on actual evaluation to determine whether such a lubricant will be beneficial in any given application.

ENVIRONMENT FOR EP ACTION

Before considering how EP lubricants function to reduce the harmful effects of metal-to-metal contact, it is desirable to examine the environment under which they must work. The most obvious symptom of boundary lubrication is an increase in friction. Friction produces heat. So the most direct way in which friction influences the lubricant environment is by increasing the temperature. This reduces viscosity and minimizes the opportunity for maintaining a fluid film. But what happens to the metal surfaces? To answer that question we must first look at the cause of friction.

A microscopic examination of a metal surface reveals that even a high degree of polishing does not produce a truly smooth surface. Machining metal leaves a surface which, under the microscope, might resemble a newly plowed field. Grinding and polish-

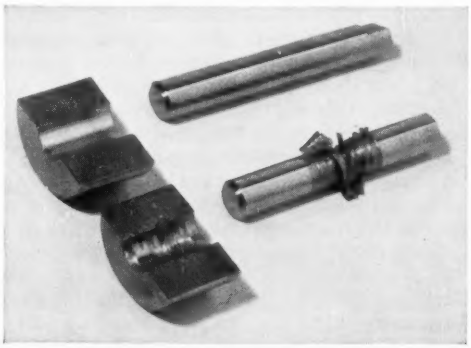

Figure 2 — Unused and "failed" specimens from the Almen test.

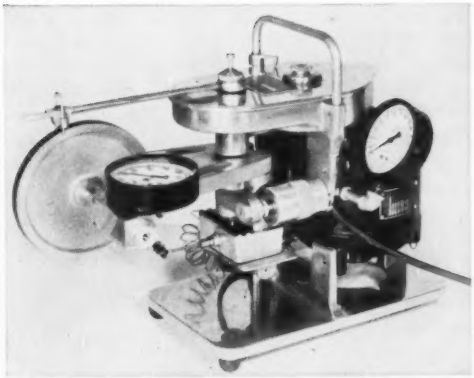

Figure 3 — The Falex Lubricant Tester. Two steel V-blocks are mounted between the "nut-cracker" loading arms. The V-blocks are pressed against a rotating steel pin by an automatic spring loading device.

ing reduce the size of the irregularities of the surface in the same way that harrowing makes the surface of a field more uniform. In either case, however, small high spots and depressions remain. Consequently, Amontons' and Coulomb's explanations of friction were based on the assumption that when two surfaces came in contact there was an interlocking of surface irregularities. Frictional work was therefore attributed to lifting of asperities of one surface over those of the other, and the level of friction was directly related to surface roughness.

Amontons' work in the seventeenth century led him to conclude that the frictional force between two objects was independent of the area of contact and proportional to the normal force holding the two surfaces together. Nearly a century later, Coulomb confirmed Amontons' findings and further concluded that friction was independent of sliding speed. This theory has received support for more than 150 years.

Bikerman[1], one of the most ardent contemporary supporters of this theory, has stated that the role of the lubricant in overcoming boundary friction is merely one of filling the low spots and in effect reducing surface roughness. While he observed that sliding was not possible between two chemically clean metal surfaces, he denied that friction was a result of adhesion. The fact that non-fusible materials, such as wood, exhibit the characteristic of friction being proportional to surface roughness can be used as an argument for this classical theory.

Other workers have disputed the theory of friction resulting from merely lifting one surface over the other. The work of Bowden and his associates at the University of Cambridge in England has probably produced the strongest rebuttal. Bowden supports the theory that friction is produced by two effects. He agrees that there is an interlocking of asperities of two surfaces but his work shows that instead of one surface being lifted over the other, the asperities of one surface tend to plow through those of the other. The force required to produce plastic deformation of the asperities as a result of this plowing action is therefore a portion of the observed frictional force. (This explanation is also compatible with the observed friction properties of non-fusible materials.) The remainder of the friction is a result of welding and shearing of minute junctions between the two surfaces.

Welding of asperities of two sliding surfaces is possible because the plowing action produces uncontaminated metal surfaces as well as high local temperatures. Bowden has demonstrated the existence of local temperatures high enough to produce welding by using the rubbing surfaces as a thermocouple. With this technique, temperatures greater than 1000°C have been observed. In other experiments he has shown that when metals are sufficiently clean, they will seize even at room temperature. Therefore, if the plowing theory is correct, welding and shearing of asperities is a logical result.

The environment under which a lubricant can function to reduce boundary friction as described by Bowden is much different from that explained by the classic friction theories. First, the lubricant can serve as a coolant to minimize the number and size of welded junctions resulting from high surface temperatures and thereby reduce that portion of the friction which results from shearing welded junctions. The lubricant can produce physically absorbed films of low shear strength on the metal surfaces and reduce that portion of the friction which is caused by plowing. Since this reduces the energy expended in the plowing process, it will also reduce the level of the peak temperature flashes and consequently the number of welded junctions will also be reduced. Still another effect can be produced by

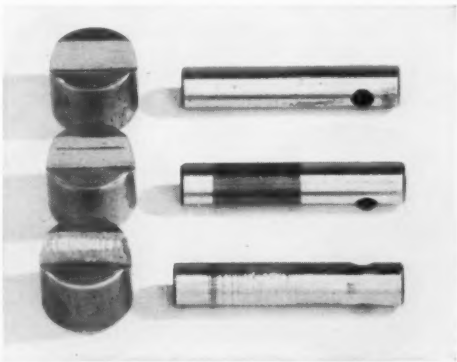

Figure 4 — New and used specimens from the Falex test.

[1] J. J. Bikerman, "Lubrication. II. Friction," Petroleum (London) 7 (1944).

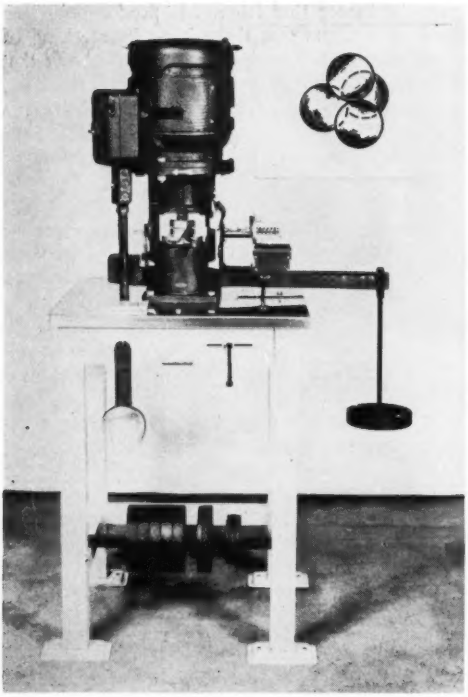

Figure 5 — The Four Ball EP Tester. Four steel balls one-half inch in diameter are placed in a pyramid. While the lower three balls are held stationary, the upper ball is rotated by a chuck. Load is applied by weights and levers.

the lubricant under the environment suggested by Bowden. The plowing by asperities and shearing of welded junctions continuously expose areas of highly reactive clean metal. In the presence of the high local temperatures which accompany this exposure, conditions are ideal for the lubricant, or additives contained in the lubricant, to react with metal. Reaction products thus formed can reduce friction by virtue of having lower shear strength than the metal to which they are bonded or by having lower melting points than the metal. In the latter case, it is presumed that the films flow when local temperatures reach their melting points and thus reduce friction in a manner similar to that of a fluid lubricant. In addition, they can fill the void spaces between asperities and produce a smoother surface. Welding can also be inhibited by these chemical films contaminating the metal surfaces.

Experience with extreme pressure lubricants indicates that they do function in the ways suggested by the environment produced by plowing and welding.

TESTING EP LUBRICANTS

It is easily demonstrated that when a gear set is overloaded, failure of the tooth surfaces can occur. On the other hand, testing of lubricants in full scale equipment is a costly and time consuming practice. In the case of large industrial equipment, full scale testing is sometimes virtually impossible, except in the field. In such instances, operators and manufacturers are reluctant to risk failure on an untried lubricant. Even when such tests are tried, it is often a problem to keep operating conditions constant over a long enough period of time to obtain a valid comparison of lubricant performance. On the other hand, high volume, less expensive equipment may be subject to manufacturing tolerances which would produce a considerable variation in test results. Therefore, in order to obtain a significant evaluation of a lubricant, a large number of tests might be required. As a result of this problem, numerous bench tests have been developed with the objective of defining the relative EP properties of lubricants, and thereby predicting their performance in full scale equipment.

Note that *numerous* bench tests have been developed. This is perhaps the strongest indication that the use of bench tests has met with little success in predicting with any degree of accuracy the performance of a lubricant in any particular application. The reasons for this failure are as varied as the testing devices themselves.

Each of the bench tests produces a rating of the lubricant in terms of the maximum load that can be applied to the sliding test specimens without massive failure or abnormally high wear rates. However, the nature of the testing devices and the procedures followed in lubricant evaluation include a wide range

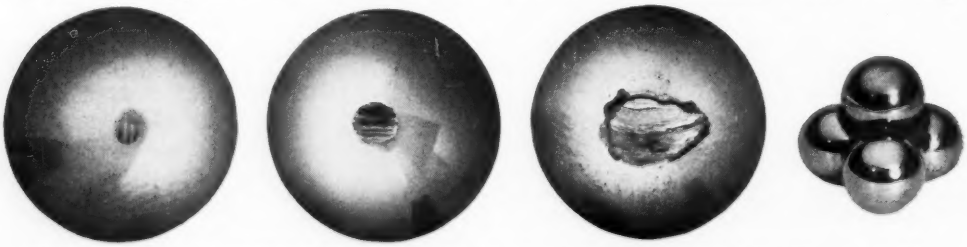

Figure 6 — Specimens from the Four Ball EP Tester showing light wear, delayed seizure, immediate seizure, and welding.

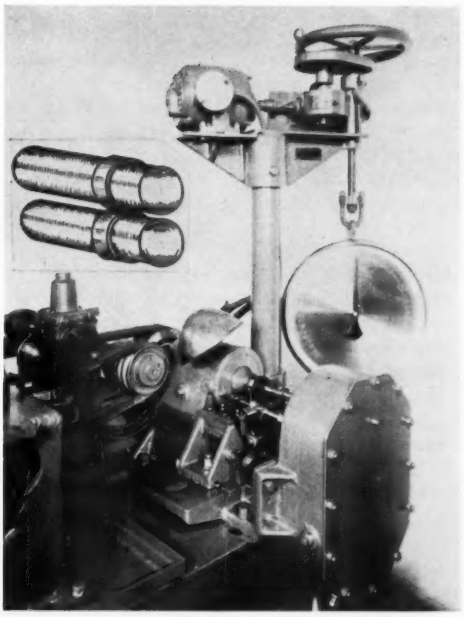

Figure 7 — SAE EP Lubricant Tester. The test specimens are two special Timken test cups. The upper and lower cups both rotate counterclockwise, but the speed of the upper cup is 14.6 times that of the lower cup, giving a combination of rolling and sliding contact. Load is applied automatically.

of variables which can influence the relative order of performance of lubricants.

Mechanical Differences Between EP Testers

From a physical or mechanical viewpoint, the following properties of the test specimens are probably of greatest importance.

Metallurgy	Surface finish
Composition	Geometry of contact
Hardness	Heat transfer paths
Micro-structure	

When it is considered that EP additives are effective by virtue of their physical and chemical action with metal surfaces, it is apparent that materials which react readily with one combination of metals may not do so with another. Thus, a lubricant which shows a high EP level when tested with steel specimens may show up poorly when tested with steel on brass. While virtually all EP tests are run with steel specimens, even relatively small variations in the amount of alloying metals used can change the effectiveness of lubricants. Hardness and microstructure of specimens of constant composition have been observed to have an effect on lubricant performance.

Surface finish of specimens influences the initial wear rate during a test, the friction between the surfaces, and hence the amount of energy released as heat. Therefore, the final relative ratings of lubricants can be influenced by the amount of break-in required of the test specimens, which is dependent on surface finish and the ability of the lubricant to produce a good break-in.

Specimens for EP tests are designed to minimize the possibility of fluid film lubrication. In most cases this is accomplished by using either line or point contact between the unloaded specimens. Line contact is achieved through the use of a cylindrical surface bearing on either a plane surface or on another cylindrical surface. Point contact is achieved through the use of spherical specimens. However, with the application of load, the specimens undergo plastic deformation and area contact results. Unfortunately, the unit loading or contact pressure is not uniform across the contact areas, a maximum pressure occurring along the line or point of maximum deformation. The relationship between the maximum load and the average load is dependent on the size and configuration of the specimens as well as the elasticity of the material. As a test progresses, wear continues at the contacting surfaces until sufficient area is available to support the applied load or until massive destruction of the surfaces occurs. With a pressure gradient across the contact area, a "wear gradient" can also be expected with most rapid wear occurring at the region of maximum pressure. A temperature gradient will also exist across this area, and it is by this combination of factors that specimen geometry influences the evaluation of lubricant performance.

In those devices which utilize line contact of the specimens, extreme care must be taken to assure that the contacting surfaces are uniform and parallel. A lack of control on this variable results in abnormal load distribution and has the same effect as a change in geometry of the specimen.

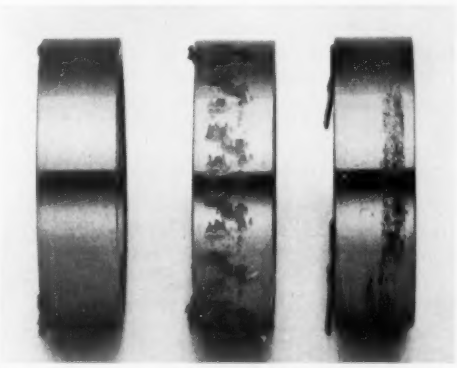

Figure 8 — An unused and two failed specimens from the SAE test.

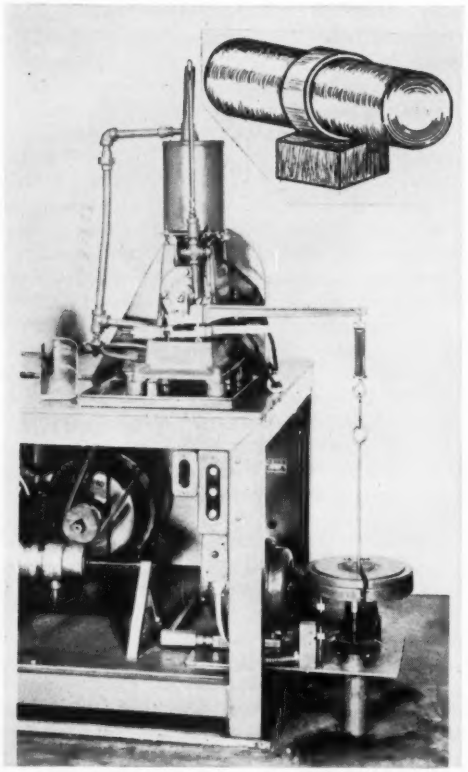

Figure 9 — Timken EP Tester. A special Timken test cup is rotated at 800 RPM on a hardened steel block. The load is applied by a system of levers which forces the block up against the rotating cup.

The rate of bulk metal temperature rise and the temperature of the specimens in and near the area of contact are related to the ability of the specimens to transfer heat away from the rubbing surfaces. This is, of course, related to the design and construction of the tester and the method and rate of lubricant application. Large differences in heat transfer characteristics exist among the various testing devices and this can contribute to the differences in test results observed with them.

Differences In EP Test Procedures

In addition to the physical and mechanical differences between testing devices which influence lubricant evaluation, there are many procedural or operating variables which have equally significant effects. Among these are the following:

Rubbing Speed
Loading Techniques
Bulk Temperature
Definition of End Point

Rubbing speed has the obvious effect of influencing the rate of heat energy release at the contact area of the test specimens. Therefore, as the rubbing speed increases, the contact surface temperature increases even though bulk lubricant and metal temperature may be little changed. As a result, the load required to produce a surface temperature in excess of that necessary to produce scoring, seizure, or rapid wear is reduced as the speed increases. In devices which have relatively poor heat transfer characteristics, the effect of speed on surface temperature may be so great that the test cannot differentiate between lubricants at one speed, while at a lower speed, they may exhibit different load-carrying ability relative to each other.

Many different loading techniques are used in EP testers. The methods include the simple case where the apparatus is started at zero load, then loaded at a uniform rate until specimen failure occurs. With this method the load-carrying ability of a lubricant has been shown to differ with the loading rate, with high loading rates producing failure of the specimens at lower loads. Unfortunately, the ratings of all lubricants are not affected by load rate to the same extent, either absolutely or relatively.

In another system, the load is applied to the specimens before rubbing is started. The apparatus is then run for a prescribed length of time and the specimens inspected to determine the extent of surface damage. If failure has not occurred, the test is restarted at a higher load, in some cases using the same specimens, while in others new specimens are used for each load increment.

Another variation of the step loading technique is one in which the apparatus is started at no load, load is applied at a uniform rate to a prescribed "break-in" level, and operation is continued for a fixed time. The load is then increased at a uniform rate to the test load level, and operation is continued at that load for a fixed time. The specimens are then inspected and if failure has not occurred, the process is repeated using a higher test load. Again in this technique, new specimens may be used for each test load increment or a single set of specimens may be used for the whole series of tests.

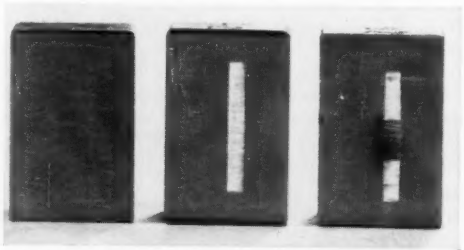

Figure 10 — An unused, an OK, and a scored Timken test block.

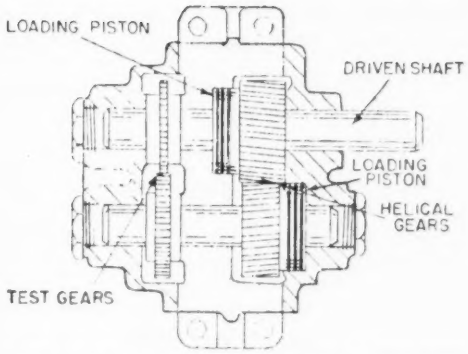

Figure 11 — Diagram of Ryder Gear and Lubricant Tester. Load is applied to the test gears by means of hydraulic pressure on the cylinders adjacent to the helical gears. Axial movement of the shafts and helical gears produces a torque which is resisted by the test gears.

Still another method is one in which the apparatus is started without load and load is applied at an uncontrolled rate by manual operation of a hydraulic loading system. In this case no break-in is used, the test is run in step-loading fashion with an inspection after each period of operation, and the same specimens are used for a complete test.

In those procedures in which step-loading is used, the time of operation at each load increment is an important variable. Usually no consideration is given to the time required to produce failure at a given load in rating lubricants. Thus, if the prescribed running time is ten minutes at each load and one lubricant fails in nine seconds while another fails after nine minutes at the same load, they are given identical ratings. With a shorter test time they would be considered different.

From the foregoing discussion it can be seen that various loading techniques are used and each can influence the performance of the lubricant. If each of these loading techniques were tried with one lubricant in one apparatus, it would be miraculous if any two ratings were equivalent. When lubricants with different chemical properties and different machines are included as variables, a correlation between machines is difficult, if not impossible.

Other operating and procedural differences add further to the confusion. Bulk lubricant temperature is one. In some procedures, the test is started with the lubricant at room temperature and no temperature control is used at all. In other cases the lubricant is heated to a prescribed starting temperature and then allowed to increase at an uncontrolled rate. In still other cases, the lubricant is supplied to the test specimens at a controlled temperature throughout the test. These variations undoubtedly affect lubricant performance.

A significant point of difference between tests is the definition of the end point. While this may be an arbitrarily defined part of a test, it is of great consequence and should be given serious consideration in evaluating lubricants. At one extreme in the scale, the end point is defined as that load which produces scoring of the test specimens. At the other extreme, the end point is defined as the load required to produce solid welding of the test specimens. Definitions of intermediate severity provide for scoring of a fixed percentage of the available area, or for a load which provides the maximum ratio of load to wear area. When it is considered that a lubricant which provides maximum protection against welding may not provide maximum protection against scoring, it is apparent that end point definitions can have a large influence on relative lubricant ratings.

The means by which the test operator identifies the end-point is another consideration. Even when

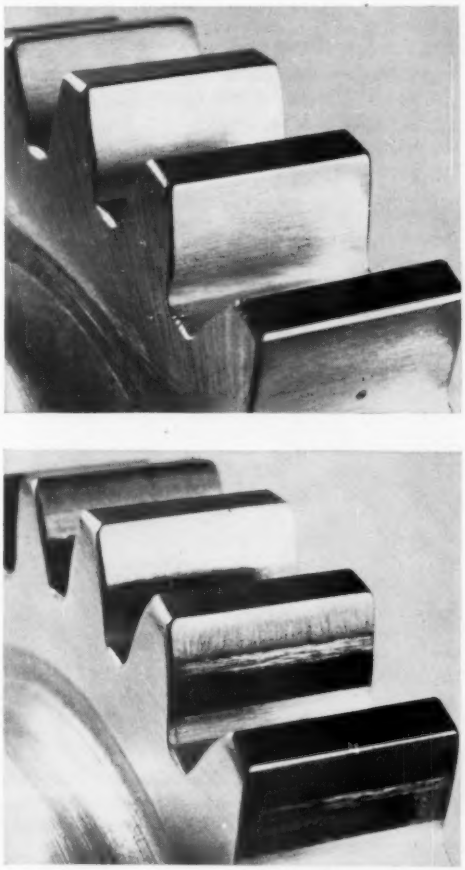

Figure 12 — An unused and a scuffed gear from the Ryder test.

the end-point is well defined, it may not be recognized easily. The operator may be required to stop the test and examine the specimens with a microscope, or he may continue running until failure is indicated by noise, smoke or sparks from the test specimens, or until a shear pin fails, or until the wear rate is so high that the load can be increased no longer. Each of these criteria for identifying the end-point represents a different degree of failure. Two lubricants which are rated in one order on the basis of incipient failure may be markedly different in their ability to protect partially damaged surfaces. Therefore, end-point recognition is just as important a variable in EP testing as end-point definition.

Significance of EP Tests

While it may seem that this discussion is placing undue emphasis on the weakness of EP tests, it is merely intended to point out the many variables which are involved in selecting a test design and operating conditions. The point which makes the problem even more difficult is that the same variables, in addition to others, exist in actual machinery where lubricants are used. Thus, to develop an EP test which correlates with only one field application would be a major accomplishment. But to expect a test to correlate well with hundreds or even several applications is expecting too much.

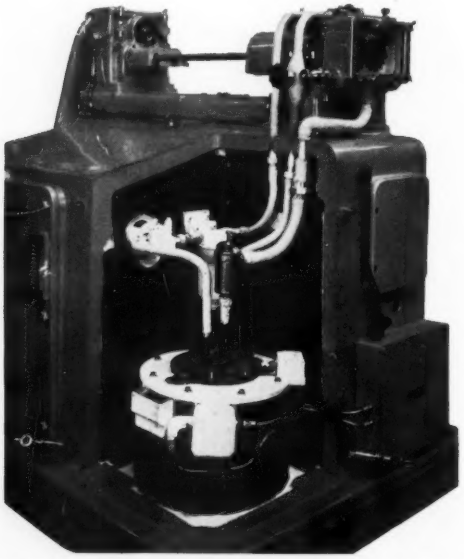

Figure 13 — IAE Gear Test. Note test gears visible through transparent cover at right of the apparatus. Four-square loading is obtained by applying a torque mechanically by means of a split shaft connecting the test gear end and the power return gear ends of the machine.

TABLE I

	Relative Load Carrying Ability, %				
Test	*1*	*2*	*3*	*4*	*5*
A	39	23	100	26	22
B	<22	31	100	78	<22
C	29	88	100	51	45
D	20	21	100	32	21
E	45	45	100	82	25
Gear Test	100	81	59	43	38

Five oils were each tested in five EP bench tests and a gear test. In each test, the best oil was rated 100 and the others were rated as a per cent of the best rating. Note the complete lack of correlation between the bench tests and the gear test.

In spite of the weaknesses of bench tests they do play an important role in EP lubricant development and selection. As stated earlier, full scale testing has its problems, too, so bench tests are used as guides in screening lubricants for service. They can be especially useful if several of the common tests are used in the screening process. If a lubricant gives good results in several EP tests, a field test can be undertaken with a relatively high degree of confidence that the EP properties will be satisfactory. On the other hand, poor results in a single bench test do not necessarily mean that the lubricant will not give satisfactory performance in full scale equipment. Therefore, EP test results must be used judiciously.

Some equipment manufacturers and lubricant consumers have found it desirable to write specifications including EP tests for lubricants to be used in either general or specific applications. These specifications are usually written to describe a material which has proven satisfactory in the intended use. However, in many cases a single type of EP test is specified, and it is assumed by the writer of the specification that the chosen test is evaluating the property of the lubricant which was responsible for its good service performance. This may or may not be correct.

EP tests in general have been shown to have poor reproducibility on the basis of strictly numerical results. On a relative basis, reproducibility is considerably better. Therefore, in writing specifications for EP properties when more than one laboratory may be required to run tests, it is desirable to specify the performance of a lubricant relative to that of

another reference lubricant of known performance rather than on the basis of an absolute number.

CHARACTERISTICS OF EP LUBRICANTS

Up to this point the theories of friction and the basis of the need for EP lubricants, as well as the means of testing for EP properties, have been discussed. But what of the lubricants? The discussion of EP tests implied that a variety of properties were characteristic of EP lubricants, and that some types of lubricants might be effective under conditions where others would not. While the relationship between chemical properties and performance characteristics is not completely understood, EP lubricants can be classified in a general manner according to the type of chemical additives used in their manufacture. The following are some typical examples of EP gear lubricants.

EX. 1. Oils containing compound of polar materials such as lard oil, the better grades of tallow and similar materials have long been used as industrial gear lubricants. Such products carry a little more load than straight mineral gear lubricants and perform somewhat better in the presence of moisture. In addition they offer some rust protection.

EX. 2. In the past and even today, an industrial gear lubricant containing a sulfurized fat such as lard oil is specified for spur, bevel or spiral bevel gears for "run-in" or "break-in" purposes. After the initial fill, a straight mineral oil may be specified for normal operating conditions.

With sulfurized fats, it is intended that sulfur be available to prevent welding by forming iron sulfide

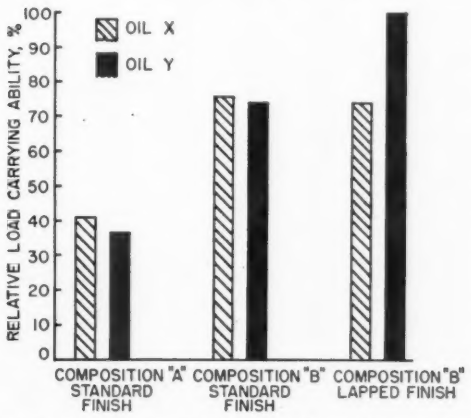

Figure 14 — Effect of specimen composition on load carrying properties. The two steel compositions used to obtain these results were from batches meeting the same specification but with slight differences in the amount of alloying metals used. Note that with one type of specimen the oils would be considered different, but with the other two they are equivalent.

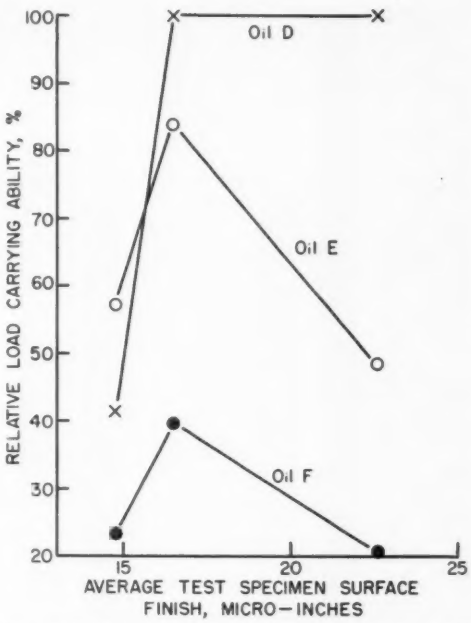

Figure 15 — Comparison of effect of surface finish on load-carrying ability of three oils. Each point represents the average of nine determinations.

at the metal to metal peak contacts. The sulfur must be sufficiently stable to prevent staining of copper and brass under certain conditions and thus is classified as "non-corrosive" sulfur.

EX. 3. A somewhat more complex formulation involves the use of lead, sulfur and possibly phosphorus and is an application of a modern theory of the function of Extreme Pressure agents. This class of gear lubricant is intended for many types of gears operating under conditions of high load and/or speed. The additives must be chosen to be active chemically under these conditions. Welding at high temperature is prevented by the formation of an easily sheared film of iron and lead sulfide and also by the formation of a low melting point phosphorus alloy. In this manner, welding is prevented over a range of operating conditions. Frequently, the mere prevention of welding is not sufficient for satisfactory lubrication and a polar compound must be used to reduce friction and afford acceptable operating temperatures.

EX. 4. The adoption of the hypoid gear by the automotive industry for high speed/low torque condition required a gear lubricant that would prevent welding under conditions differing radically from those encountered before. In this type of gear, the tooth pressure is high, coupled with a pronounced wiping effect. Thus it is easy to visualize

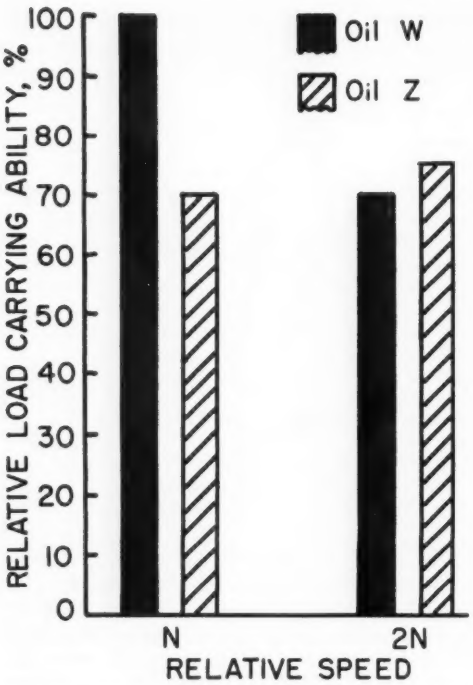

Figure 16 — Effect of speed on relative load-carrying ability in a standard EP test.

that the proper lubrication of the hypoid gear in high speed/low torque conditions must be accomplished under new conditions of temperature and pressure. To do this, it has been found necessary to choose additives to prevent welding but — and this is the important point representing development and application of a new theory — the temperature and rate of formation of the easily sheared film must be regulated and controlled. This can be done by using a lead soap and active sulfur. This class of gear lubricant causes high wear under high torque-low speed conditions. The active sulfur is the key to this type of formulation. The sulfur is bound in a rather loose chemical manner and controlled to be available at the required temperature and in the proper amount. It should be obvious that sulfur, when present at this high level of activity, would stain copper and thus, in this case, it is designated as the "corrosive" type. This type of lubricant is particularly effective when shock type loading is a factor.

EX. 5. With the widespread application of the hypoid gear in passenger car and truck service (high speed/low torque and low speed/high torque conditions) it was necessary to modify the lubricant described in (4) to accommodate the more severe conditions of tooth pressure, wiping action and temperature and to prevent wear. Again, a more specialized application of the theory that the temperature and rate of formation of the easily sheared film for a particular range of operating conditions was required.

This type of gear lubricant is actually the "all-purpose" or "multi-purpose" type as covered by Military Specification MIL-L-2105 Universal Gear Lubricant. This specification was developed as the result of cooperative effort with the automotive manufacturers and the oil industry. The specification is significant because two full-scale laboratory axle tests form a part of the qualification testing of lubricants submitted for Ordnance Department approval against MIL-L-2105.

In the formulation of lubricants for this service, additives containing chlorine, sulfur and phosphorus are employed. The essential variation from (4) is that the formation of iron chloride which prevents welding is catalyzed or speeded up by sulfur to insure satisfactory service under very severe operating conditions. The role of phosphorus is similar to that previously described.

EX. 6. This type of gear lubricant is similar to that in (5) since the lubrication of hypoid gears is the primary purpose. From an additive standpoint, the principal change is the inclusion of a

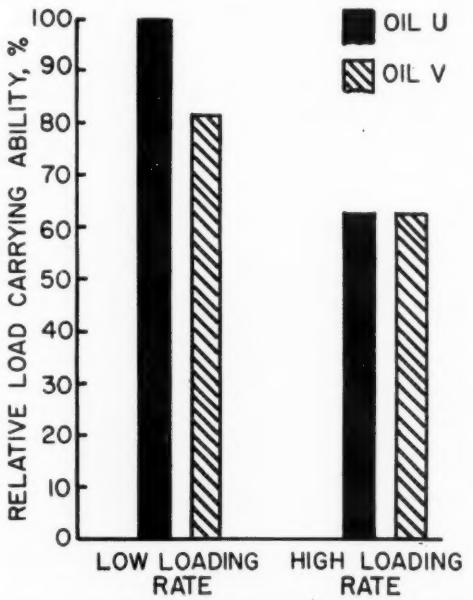

Figure 17 — Effect of loading rate. The high loading rate was about four times as great as the low loading rate. While the two oils were given different ratings at the low loading rate, they were equivalent with the high loading rate but at a lower rating level.

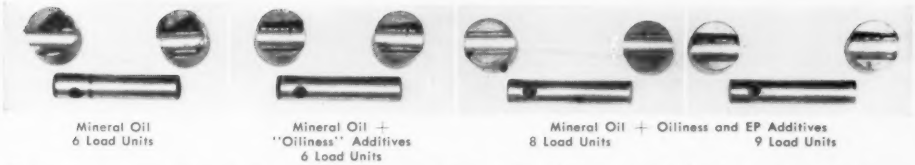

Figure 18 — An illustration of the wear-reducing properties of EP additives on soft bearing metals under severe operating conditions. Tests were run for two hours at constant speed and lubricant temperature.

lead soap and the omission of phosphorus. This type of lubricant can be made to meet MIL-L-2105 and will handle more severe operating conditions than the products described in Example 5.

The foregoing discussion of lubricant types was related primarily to gear lubrication and the nature of the materials used to impart the particular properties needed, but any of the types of additives mentioned might be found in a variety of specialized lubricants for particular applications. In the application of these additives, the base lubricant can vary through all available viscosity grades of paraffin and naphthene petroleum oils as well as all types of greases and even synthetic lubricants. Conditions of operation other than those requiring EP properties determine the physical and chemical properties required of the base lubricant.

EXAMPLES OF EP LUBRICANT APPLICATIONS

Automotive

Automotive applications of EP lubricants are undoubtedly the most familiar, and consumption in this field amounts to the largest percentage of the total EP lubricant production. Virtually all the fluid lubricants used in the automobile can exhibit EP properties.

The hypoid rear axle has the most severe EP requirement and has been the basis for most of the research on EP lubricants which has been conducted in the last twenty-five years. However, the requirements for rear axle lubricants are continuously changing with new developments in the automotive industry. On one side, improved gear manufacturing methods and treating processes tend to reduce the level of EP requirements, but these may be counteracted by more powerful engines and smaller gears.

Manual-shift transmissions are sometimes lubricated with straight mineral oils, but usually have an EP lubricant specified. While the EP requirement of the helical gears used in transmissions is not as high as that of a differential, they frequently use the same type of lubricant.

Automatic transmissions present some of the more complex requirements for EP lubricants. In this application, the lubricant must serve as a gear lubricant and a hydraulic fluid; it must lubricate bearings, pumps, valves, metallic and non-metallic clutches and bands, and seals. It must be an all-climate lubricant functioning at temperatures from sub-zero to more than 300°F., and it must retain its properties up to 25,000 miles. In order to obtain the characteristics required of this highly specialized lubricant, a variety of additives other than EP additives may be required. Yet, they must all be compatible and carefully balanced to assure that a material added for one purpose will not counteract those materials added for other purposes.

Power steering systems have requirements similar to those of automatic transmissions except, of course, for power transmitting gears. As a result, automatic transmission fluid is normally used as the hydraulic fluid and lubricant. The EP properties of this material are useful in reducing wear of pumps, pistons, valves and other moving parts of the system.

EP properties are also found among the desirable characteristics of some heavy duty motor oils. In the modern high speed, high powered engine, loads have been imposed on valve lifters, camshafts, and rocker arm shafts which cannot be supported by

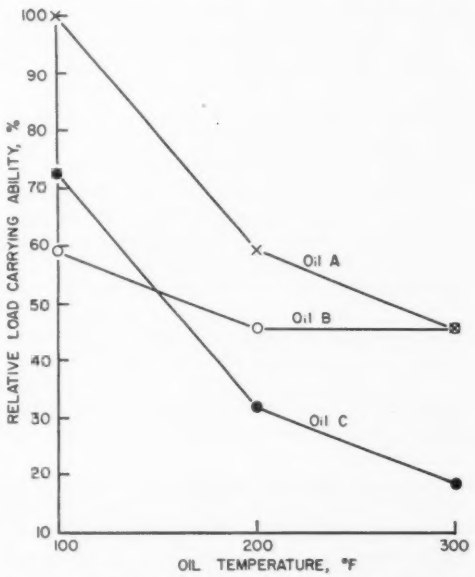

Figure 19 — Effect of temperature on relative load-carrying ability in an EP bench test.

means of a simple oil film. To prevent rapid wear and early failure of these parts, it has been necessary to supply lubricants which provide a chemical film on the rubbing surfaces in the absence of a full oil film. The problems of supplying such a motor oil are complicated by the fact that the oil is subjected to the high temperature of cylinder walls which promotes decomposition of additives. In addition, the oil is continually being contaminated by unburned fuel, fuel decomposition products, and moisture. Hence, additives selected for this application must have the ability to provide protection to sliding surfaces when the oil is clean and new and must have the stability to withstand the effects of contamination in use and continuous exposure to high temperatures.

Marine EP Turbine Oils

For many years marine turbine reduction gears were lubricated with premium grade hydraulic oils. While these oils were inhibited to prevent rust and oxidation, their EP properties were equivalent to straight mineral oils. Recent experience has indicated that EP additives may improve break-in properties in this application and increase the life of gears under normal service conditions. Therefore, there has been a recent increase in the demand from ship-builders and owners as well as the Navy for marine EP turbine oils. With the addition of EP properties to this class of oils, all their former desirable characteristics have been retained.

Industrial EP Lubricants

Industrial EP lubricants include oils as well as greases. Oils are provided in a wide variety of viscosity grades and several additive types to meet the requirements of virtually all methods of application and operating conditions. EP greases are usually provided in the range of consistency encompassed by NLGI grades 0, 1 and 2. Industrial lubricants ordinarily do not have the requirement of wide temperature range operation and therefore in most cases it is possible to select the viscosity or consistency most suitable for the prevailing operating conditions.

One of the chief considerations in industrial lubricant formulation is providing additives which can cope with contaminants. While it may be relatively simple to devise a formulation to meet the EP and other requirements, the lubricant must be able to withstand contact with water and numerous process contaminants.

Industrial gear lubricants may be used in small systems where the gears are splash lubricated from the sump, or they may be placed in complex circulating systems with capacities of thousands of gallons. In either case, the plant or equipment operator demands assurance that the lubricant will serve for long periods of time without replacement (sometimes literally years) and still protect his valuable machinery. To meet this requirement, base stocks and additives must be selected carefully to provide long term stability of all the properties of the lubricant with a minimum of deterioration or additive depletion. Water separation and filtration characteristics must be considered. Additives cannot be susceptible to leaching by water and must not promote the formation of emulsions.

Cutting oils are another type of industrial EP lubricant which have special properties and problems. In addition to the conditions of contamination which are encountered, the color and corrosiveness of cutting oils must be given careful consideration. In some applications, a transparent oil is required so that the machine operator can observe his work. This places a limitation on the type of EP additives which can be used to improve cutting tool life. On the other hand, some additives which might be very desirable from the point of improving tool life can be completely unsuitable because of their characteristics of staining or corroding the freshly machined metal surfaces. There must be close cooperation between the lubricant supplier and the customer to provide the product best suited for a particular machining operation.

The lubrication of plain journal bearings is another field where EP additives have found application. EP additives are used to provide a margin of safety for those operating conditions in which a fluid film cannot be maintained. Such situations can exist when a period of high speed, high temperature operation is followed by low speed operation, a sudden stop and restart, or the application of shock loads. Under these conditions the EP lubricant keeps friction at a minimum, and prevents bearing overheating and excessive wear.

CONCLUSION

It has been the aim of this article to present an idea of what is known and what is not known about EP lubricants. It is hoped that the reader will have gained a better understanding of the complexity of such materials and their application. In closing, it is believed that the following statements are worth emphasizing.

1. The EP requirements of any application are hard to define.
2. Any given EP test may not measure the properties of a lubricant which are beneficial in a specific application.
3. The cooperation and experience of the consumer, the equipment manufacturer, and the lubricant supplier should be used to full advantage in specifying a lubricant for a given machine.
4. An EP lubricant can't compensate for a poor design.

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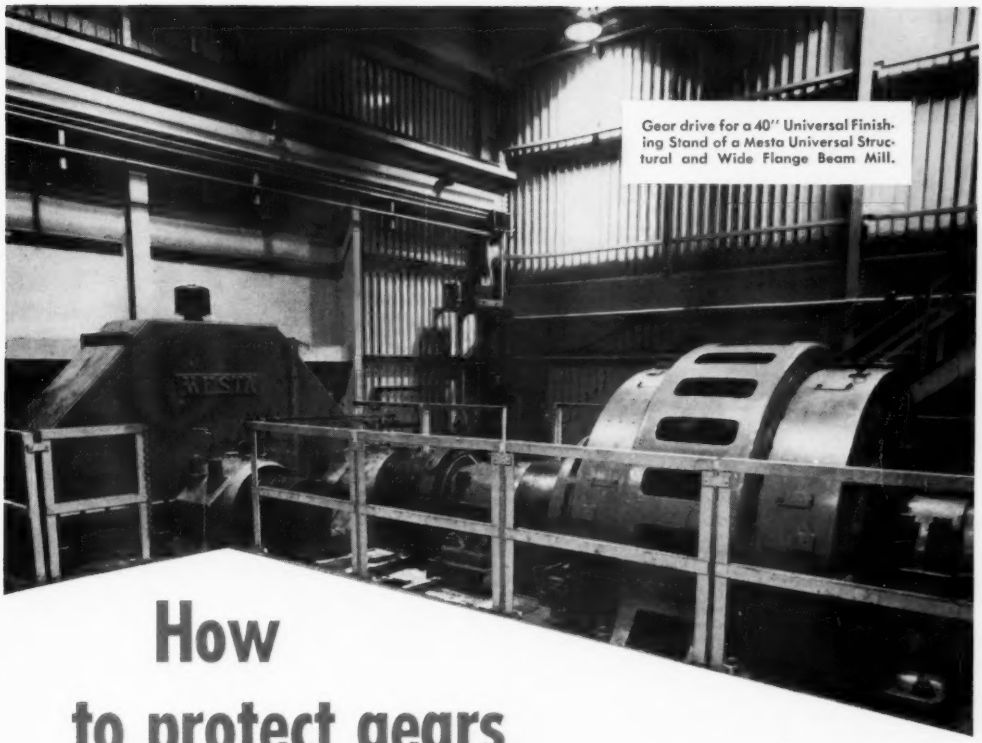

Gear drive for a 40" Universal Finishing Stand of a Mesta Universal Structural and Wide Flange Beam Mill.

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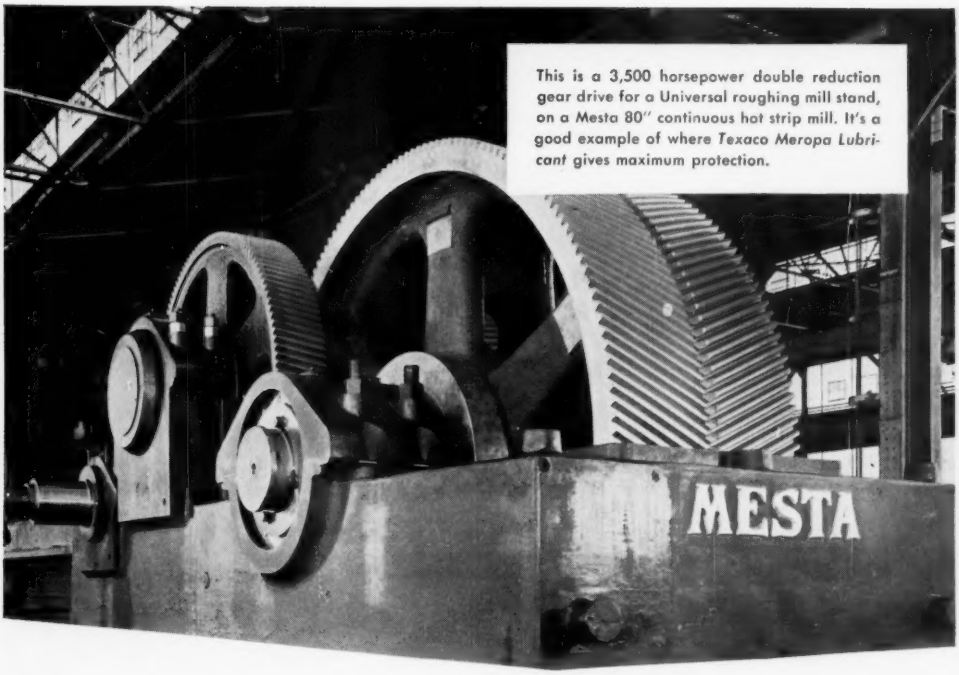

This is a 3,500 horsepower double reduction gear drive for a Universal roughing mill stand, on a Mesta 80" continuous hot strip mill. It's a good example of where *Texaco Meropa Lubricant* gives maximum protection.

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